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BREATHING APPARATUS FOR SELF-RESCUE FROM AREAS
CONTAMINATED BY IRRESPIRABLE GASES

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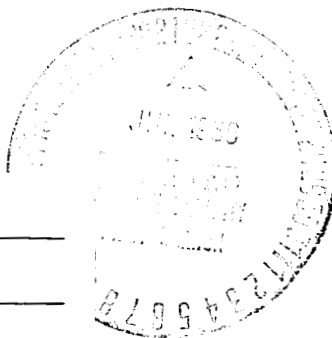
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BREATHING APPARATUS FOR SELF-RESCUE FROM AREAS
CONTAMINATED BY IRRESPIRABLE GASES

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ABSTRACT: Describes a portable emergency oxygen generator
based on the reaction of alkali peroxides with water.

For several years, the mining industry has been making efforts to mini- /1426*
mize the hazards and, hence, the number of accidents of miners whose work
is already quite difficult. It is, therefore, encouraging that all proposals and
inventions which tend to promote such efforts are receiving increasing attention.
While the probability of disasters is being minimized through technological
improvements in the mines themselves, work is also in progress on the develop-
ment of rescue techniques which will reduce the number of victims to that lower
limit which, considering the impotence of human energy and willpower in a
struggle against the fury of elements, unfortunately cannot be reduced any further.
In the case of rescue operations following firedamp explosions, in particular,
it should be borne in mind that although the miners in the center of explosion
and its immediate vicinity perish as a result of mechanical and thermal effects
and nearly always are to be considered as lost, medical evidence shows that a
far greater number of miners are killed by the afterdamp, i.e., the carbon
dioxide- and carbon monoxide- containing combustion gases which invade the pit
tunnels and shafts after an explosion. In other words, these people are victims
of asphyxiation or carbon monoxide poisoning, a fact first pointed out by
J. Haldane [1] (Oxford).

It is thus obvious that the success of a rescue operation, either from the /1427
surface or by self-rescue, depends essentially on the availability of equipment
enabling the user to breath for extended periods, in an area filled with irrespi-
rable gases. The first positive achievement in efforts to provide such safety
equipment is represented by the "Pneumatophor" developed through the efforts
of Finance Director (Cameraldirektor) v. Walcher-Uysdal following the terrible
mine disaster at Hohenegger Schacht Karwin (March 16, 1895). The original
concept of this device was that of a self-rescue apparatus.

Subsequently, equally significant devices based on the same principle but
of new design and incorporating various improvements were built by Imperial-
Royal Mining Consultant Mayer in Mährisch Ostrau (now Moravska Ostrava,
Czechoslovakia), Mine Director Mayer in Herne-Shamrock and Fire Brigade
Chief Giersberg in Berlin. All these devices have in common the characteristic
that they are based on the use of highly compressed oxygen and the simultaneous
absorption of exhalation products, mainly carbon dioxide, by caustic alkali.

*Numbers in the margin indicate pagination in the foreign text.

The caustic is used either in the form of an aqueous solution, with a reactive surface highly developed by means of different spreading systems such as "Loofah"- or nickel wire mesh pads, or in solid form. Unfortunately, the use of compressed oxygen contained in steel cylinders also requires various mechanical devices such as pressure reducing valves, etc., because of which such equipment, despite thorough inspection, is frequently unreliable and complicated; in addition, it is fairly heavy and costly. Furthermore, the user must be familiar with the operation of the equipment to make the best use of its advantages also under emergency conditions. Even the new high-performance Dräger shut off and pressure reducing valves have not completely overcome these difficulties and shortcomings. In fact, this higher performance, i.e., the refinement in the control of these valves, has also increased the danger of their small-bore passages becoming plugged with rust, sand or other dirt.

For all these reasons these devices cannot be used for self-rescue, i.e., they cannot be made available to every miner to enable him, under emergency conditions, to rescue himself without delay and without having to wait, in agonizing uncertainty, for a successful rescue operation from the surface. Unfortunately, according to information obtained from mining circles, even after several years of practice, apparatus based on the cited systems has not been successfully used in real rescue operations under emergency conditions. We therefore deemed it worthwhile to attempt the development of a new device—a real self-rescue apparatus—based on principles not previously used. The present paper deals with the results of nearly four years of intense experimental activity. The decision to publish this work was made after we convinced ourselves that the new apparatus did, in fact, perform as expected considering its low cost.

Certain aspects of the history of the development of our design are of general interest. The design principles considered were those consistent with the idea of a self-rescue apparatus, i.e., low weight, small volume, simple operation combined with reliable functioning, long life and minimum cost. Because of the unavoidable shortcomings and disadvantages associated with the use of compressed oxygen, it seemed desirable to supply this gas to the user in some other way, i.e., to generate it when required through a chemical reaction in an amount approximating the breathing needs of the user. This would obviate the need for heavy and complex valves and pressure reducing devices. First, sodium peroxide was considered as the oxygen source. The reaction of this compound with water under suitable conditions gives rise to vigorous oxygen evolution with formation of sodium hydroxide which can be used to absorb carbon dioxide. Because of irregular oxygen evolution from commercial powdered peroxide which made it difficult to regulate the gas stream, another form of peroxide was needed. Such a new form was provided by melting the peroxide in iron crucibles and pouring the melt into rod- or sphere-shaped molds. In this process, the peroxide dissolves an appreciable amount of iron, apparently in the form of sodium ferrate, which on dissolution in water also generates oxygen with formation of a fine iron oxide sludge. This sludge catalyzes the decomposition of the alkaline hydrogen peroxide solution obtained initially from sodium peroxide at a normal water temperature.

At first, sodium peroxide rods alone were used, according to the principle of self-regulating, continuous gas evolution type equipment; later, the oxygen produced in this manner was supplemented by periodical addition of sodium peroxide spheres to the reaction water with the aid of a manually operated device. Neither method produced a uniform stream of oxygen. By means of two mica-insulated valves, the exhaled air was forced to flow over a sufficiently increased surface area of the caustic formed in the reaction. Although this did not completely remove the carbon dioxide it did reduce its concentration in the air to an acceptable percentage similar to that achieved in the equipment cited in the introduction.

As we had later learned from the patent literature, Balthazard and Desgrez as well as Jaubert worked simultaneously and independently on devices based on the same principles. **Balthazard and Desgrez** developed an apparatus in which oxygen was generated by portionwise addition of alkali peroxide cubes (prepared under high pressure and containing small amounts of peroxide) to the reaction water. At first, the addition device was actuated by a small battery-powered electrical motor and later by a watch mechanism. Here, too, the caustic formed was used for carbon dioxide absorption. Because of its weight, complex design and high price, the apparatus built by these two workers was obviously unsuitable for self-rescue. This apparatus seems to be designed particularly for use in submarines, diving bells, etc.

/1428

In this apparatus as in ours, the rapid rise in temperature of the reaction solution causes considerable difficulty. The gas stream heats up in contact with this solution and, being saturated with aqueous vapor, causes considerable discomfort to the user already at a temperature of 40 - 50° C. Desgrez and Balthazard eliminated this defect by vigorously cooling the inhaled air with low-boiling methyl chloride. Their apparatus is provided with a small cylinder containing this material in the liquid state. When cooling is required, a valve is opened to reduce the pressure to atmospheric pressure thereby causing the methyl chloride to boil continuously. Naturally, in view of the goal we had set for ourselves, we could not make use of this expedient. Our attempt to cool the air by lengthening the tubing or the breathing bag which is located between the mouthpiece and the gas-generating container were only partly successful. Furthermore, carbon dioxide absorption was unsatisfactory during the initial use period, because at this point in time the caustic soda solution is still quite dilute. In the earlier-mentioned devices, too, the initially high carbon dioxide content of the inhaled air tended to cause difficulties.

For the elimination of the high moisture content of the regenerated air, we considered the use of an inoffensive absorbent such as dry calcium chloride realizing that this material very probably would liquefy and plug the system. We also thought that it should be possible to remove, by means of a suitable absorbent such as sodium peroxide, at the same time the troublesome moisture and the last traces of carbon dioxide that escaped absorption by the caustic soda solution. Sodium peroxide also has the advantage that absorption would occur with generation of additional oxygen. From this thought soon came the idea to absorb the exhalation products exclusively by means of dry sodium peroxide with simultaneous oxygen evolution. Thus, we had suddenly developed a surprisingly simple new principle for the design of the apparatus. Although this

principle was very attractive, the construction of such an apparatus in the work period that followed proved to be very difficult and tedious. Again it became necessary to use the peroxide in a suitable shape. This was indicated by a number of preliminary attempts with sodium peroxide that was molten and then granulated or powdered and then shaped, under high hydraulic pressure, into a variety of fine wire screens, and also with Jaubert's peroxide tablets. In the latter case, the desired reactions (absorption of water vapor and carbon dioxide) initially proceeded smoothly but then, after a short time, ceased. This was due to the fact that the reactions actually occurred only on the peroxide surface and that even a very thin coating of the reaction products, i.e., sodium carbonate and sodium hydroxide and possibly also sodium peroxide hydrate, on the surface of the unreacted peroxide was able to prevent the reaction of the latter with the respiratory gases. For this reason, we needed a peroxide having a certain particle size which would not excessively interfere with the flow of exhaled air and which was also highly porous to prevent the respiratory gases from reacting with the peroxide only on its surface. The electrochemical firm "Natrium" in Rheinfelden kindly agreed to prepare the desired product.

In preliminary tests we established that, at about 35° C, our sodium peroxide reacted instantly and nearly quantitatively with the moisture present in a water vapor-saturated stream of air and in moisture-laden carbon dioxide, pure or diluted in any proportion, generating oxygen; however, dry carbon dioxide reacted only with slightly preheated peroxide. These reactions occur according to the following equations with evolution of considerable heat resulting in temperatures of 360° C and higher; with pure carbon dioxide, the heat is so intense that the materials melt and become glowing hot. As can be seen from these equations, it is unfortunately not possible to regenerate the total amount of oxygen consumed in the formation of the exhalation products. In fact, as shown by equations I and III, whereas the oxygen present in water is completely regenerated, only one half of that in carbon dioxide is obtained. The yield of oxygen appears to be even lower considering also equation II which indicates direct absorption of carbon dioxide by sodium peroxide without oxygen formation. Actually this is not so. Because of the high reaction temperature, the molecule of water formed is not retained by sodium carbonate as water of crystallization but reacts with another molecule of peroxide according to equation I, this time with oxygen evolution. Important in estimating the difference between the amount of oxygen consumed in breathing and that partly regenerated according to the above equations, is the ratio of carbon dioxide to water vapor contained in the exhaled air. Assuming average figures for these two exhalation products, it is easy to calculate that approximately one-third of the average amount of oxygen actually needed for the oxidation processes in the blood must be supplied to the rescue apparatus as free gas, either also generated chemically at the time of use or taken from a supply of compressed gas, whereas two-thirds are regenerated from the exhalation products by the sodium peroxide in the apparatus.

The apparatus is therefore divided into two parts: an absorption and regeneration section and an oxygen-generating section. These sections are

either completely separated or they are kept in a common housing. There are no valves or mechanical parts that must function while the apparatus is in use. Since alkali peroxides decompose when exposed to moist air, they obviously must be kept hermetically sealed off before use. The best method of sealing the container is by soldering. When needed, such containers are readily punctured. Figure 1 shows a view in cross-section of such a self-rescue apparatus. /1429

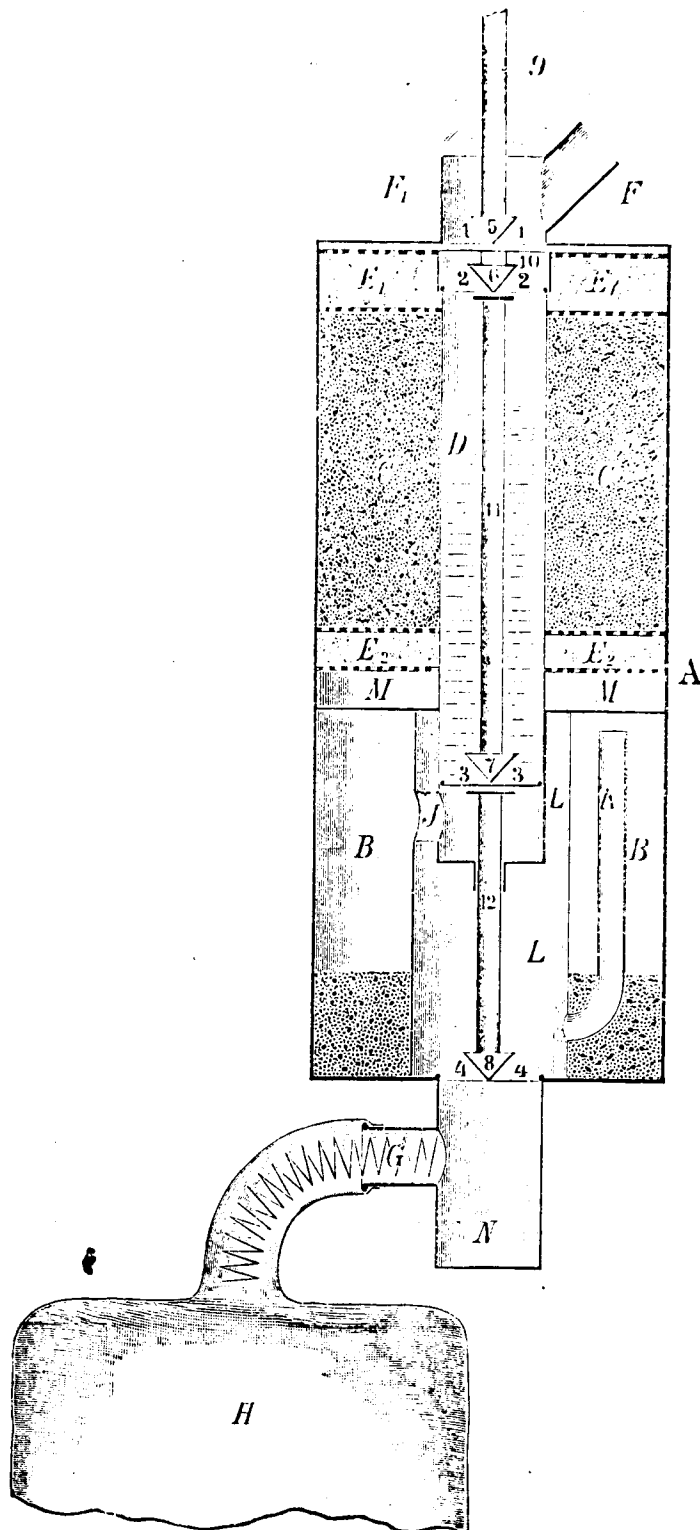


Figure 1. (Approx. 2/3 of actual size).

The common housing A contains the following: an annular chamber C filled with granular peroxide and separated on both ends from the adjacent filter chambers E₁ and E₂ by wire screens; an annular oxygen-generating chamber B, and a centrally located tubular water container D which communicates with B through connection piece J. D is hermetically sealed by thin lead sheets (2 and 3) soldered to its top and bottom ends; it contains the required amount of water (50 cc). Housing A is surmounted by a small domed attachment F₁ which is connected, through tube F and flexible tubing, with a mouthpiece or a breathing mask. Breathing bag H is attached to the lower end of the housing by means of connecting tube G.

Free communication between F₁ and E₁, and L and G or H is prevented by soldered sheet seals 1 and 4. The apparatus is started by pushing down the piercing mechanism 5 - 12. This mechanism consists of push rods 9, 10, 11, 12 bearing on their lower end piercing cones 5, 6, 7, 8 which rest on the upper surface of sealing sheets 1, 2, 3, 4, the lower surfaces of these sheets being in contact with the upper end of push rods 10, 11 and 12. The apparatus functions as follows: by pushing down rod 9, which is fitted with a handle, all four sealing sheets are pierced. The water contained in D flows through J into B where it comes in contact with the peroxide thereby generating the additional or supplementary oxygen required for breathing during the foreseen length of time. This oxygen passes through K, L and G into H. Simultaneously, the mask or the mouthpiece including the nose clip is put in place. The exhaled air passes through F, F₁, filter E₁ and peroxide layer C where carbon dioxide and water vapor are absorbed with regeneration of most of their oxygen. The air, which is now free of exhalation products but does not contain the required amount of oxygen, flows through L and G into bag H, where it mixes with the supplementary oxygen contained therein. At the next inhalation, the air returns following the same path. When the opening mechanism is actuated, the cap located at the upper end of the water tube forms with the tube edge a gas-tight seal thereby preventing the respiratory air from following route D, J, B, K through the apparatus thus by-passing absorption layer C. Since filters E₁ and E₂ are in contact with the peroxide, they obviously must be made of incombustible material (asbestos). The purpose of these filters is to retain atomized sodium hydroxide, entrained in the form of a mist by the oxygen formed, and a fine dust of sodium peroxide or carbonate stemming from C.

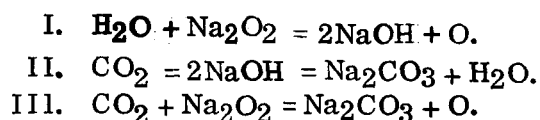
The results obtained with this design were quite satisfactory. Various minor defects were readily eliminated through appropriate improvements. However, in view of the development of a simpler apparatus described in the following, these improvements will not be discussed here.

It is easy to understand that replacing sodium peroxide with higher peroxides showing similar behavior with respect to the reaction with carbon dioxide and aqueous vapor, would obviate the need for this supplementary oxygen; this would also further simplify the design and facilitate the starting of the apparatus. Such higher peroxides should therefore differ from sodium peroxide only in that they possess a more favorable ratio of oxygen atoms to metal atoms, assuming no change in valence. Two such compounds are described in the literature: potassium tetroxide, K₂O₄, and sodium

potassium peroxide, NaKO_3 . Although the former contains three times as much available oxygen as sodium peroxide, Na_2O_2 , it is not suitable, because of its high price and the fact that its conversion into potassium carbonate in the apparatus occurs with formation of a highly hygroscopic substance which probably would liquefy and thereby greatly reduce the gas permeability of the absorption layer. For these reasons, we decided to use sodium potassium peroxide in the previously described dust-free, coarse, porous form.

As indicated by the following equations, this compound provides twice as much oxygen as sodium peroxide. Since the amount of oxygen available from sodium peroxide is only 1/3 less than the actual breathing requirements, a certain amount of sodium potassium peroxide should be more than sufficient to convert the exhalation products formed during use of the apparatus back into usable oxygen and, hence, no additional oxygen should be required.

These equations are as follows:



As can be seen, twice the amount of oxygen present in water vapor and all the oxygen in carbon dioxide are liberated in the regeneration process. This ensures not only that the exhaled air will be converted into adequate breathing air, but that this air will be enriched in oxygen. This is certainly of interest considering that the breathing bag may leak or permit loss of gas by diffusion.

The self-rescue apparatus built on this principle is shown in vertical cross-section in Fig. 2 and in full frontal view in Fig. 3.

It consists of a cylindrical sheet iron container A sealed at the ends by cover D_1 and bottom sheet D_2 . D_1 and D_2 are also made of sheet iron and both are joined to A by soldering. Domed attachment F_1 rests on D_1 and communicates through tube F with the breathing tube and mouthpiece; connecting piece G, soldered to the bottom sheet, communicates with the breathing bag through side arm H.

In this case, too, critical openings in the unused apparatus are sealed by lead sheets 1 and 2 held in place by soldered joints. Immediately before use, these sheets are punctured by piercing mechanism 5, 3, 6, 7, 4. This part of the apparatus consists of two push rods 5 and 7. Rod 5 passes through F_1 and carries at its upper end a handle and at the bottom piercing "crown" 3. Rod 7, located inside the apparatus, is connected at its upper end with plate 6, this plate being adjacent to lead seal 1, and at its lower end to a second piercing "crown" 4. Prolonged contact between the sharp edges of this crown and seal 2 could easily damage the latter if the apparatus were exposed to shock. To prevent this from happening, the crown is pushed upward by means of a spring located above it, and plate 6. S_1 and S_2 are two "plate filters" each consisting of a pair of perforated sheet iron plates with holes surrounded by 2-mm high edges or rims. These holes are arranged so that those on one plate do not face those

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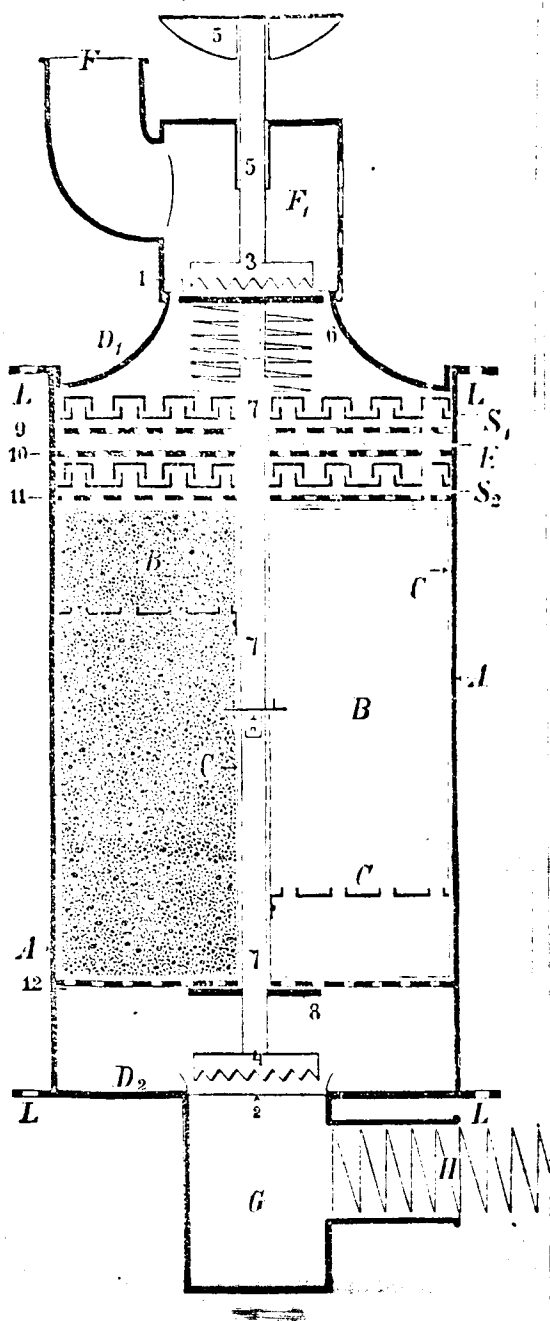


Figure 2

When not in use, the apparatus is stored in a sheet iron case fitted with a handle and in this condition should be given to the miner at the beginning of his shift. Naturally, the apparatus can be prepared for use in just a few seconds: all that is required is to remove the protective case, pierce the soldered seals, fasten the carrying strap, and put the mouthpiece and nose clip in place. At

on the other. The air passing through these plates is thereby forced to follow a zig-zag path and to change direction frequently. This results in excellent distribution of the incoming air over the entire cross-section of the apparatus, a requirement proved to be essential for efficient use of the peroxide. Furthermore, the lower plate filter also acts as a dust trap. Extremely fine dust consisting mainly of potassium sodium carbonate and, to a lesser degree, of peroxide particles is retained on a specially fabricated asbestos filter located between the two plate filters and separated from them by two wire screens 9 and 10. Chamber B, also supported by two wire screens, 11 and 12, holds the sodium potassium peroxide filling (250 g) of the apparatus. While reacting with the exhalation products, the peroxide sinters and cakes markedly which interferes with the flow of air. This problem was solved by use of a light-weight rack provided with a few narrow perforated support trays C.

The plate located beneath bottom screen 12 serves only to distribute the stream of air coming from G.

The coil spring at H prevents the kinking of the breathing bag, which is attached at this point. Such a spring is used also in other apparatus of this type. Since the apparatus becomes quite hot during use, contact with metallic parts is prevented by covering them with an insulating jacket made of asbesto board or "papier mâché." Four holes L are provided in the cover and bottom for receiving the carrying strap. They are arranged so that the strap, at the same time, also supports the insulating jacket which consists of two parts.

/1431



Figure 3

a mine official from the surface who wants to inspect an area filled with irrespirable gases and in many other situations such as water well or sewer line inspections. This simplified version differs from the apparatus described in that the sodium potassium peroxide is not sealed into the apparatus, but is stored in a separate container. This obviates the need for a piercing mechanism; furthermore, to facilitate the filling operation, cover D₁ and tube G are fastened to housing A by means of screws. After use of the apparatus, these two parts are detached by removing the screws; the plate filters and filter chamber E are taken out and the reaction product formed (sodium potassium carbonate and the corresponding hydrate) are dissolved in water. Since it is also possible to remove the rack and the lower screen, the empty apparatus can be thoroughly cleaned and dried. Except for the asbestos filter, all parts can be reused and the apparatus may be filled at the mine itself. Naturally, this should always be done just before use. It is important to remember that the peroxide should not be exposed to moisture-laden air more than absolutely

this point, the breathing bag is normally nearly empty. Hence, if the user ceases to breath in the surrounding air at an instant when he has just completed an exhalation, it can easily happen that the apparatus will not provide a volume of gas sufficient for the next inhalation. This means that the lungs will receive insufficient oxygen and breathing will be difficult. To prevent this difficulty, the user is instructed to partly fill the breathing bag by twice blowing into it before putting the nose clip in place. In our opinion, this simple method is better than to fill the bag with chemically generated oxygen as in the case of the apparatus previously described.

/1432

An apparatus of simpler design will be built for situations not involving a sudden, unforeseen need, i. e., for cases where the user has several minutes to prepare the apparatus. For example, such an apparatus will be useful to

necessary. The only other design detail of these two types of apparatus to be mentioned here is the breathing tube which connects the mouthpiece to tube F. The mouthpiece consists of a spindle-shaped rubber plate which fits between the lips and the teeth. This breathing tube must be flexible and readily follow normal head movements but must never kink or permit a significant reduction in its useful flow cross-section. The so-called corrugated tubes consisting of coiled wire embedded in heavy rubber were found to be too stiff and to cause a cramp-like pain in the lips. We used, with excellent results, a cylindrical tube made of the same thin, rubber-coated fabric from which the breathing bag is made. Kinking was prevented by inserting into the tube a right-handed and a left-handed, steel wire coil. The net-like structure resulting from this coil arrangement also seems to prevent creasing of the fabric between two coil turns. Such a breathing tube is very light and follows head movements without offering any significant resistance.

A brief comment is now in order concerning the physiological sensations of the user of our apparatus. /1433

No difficulty is expected from the fact that, in cases where the user is engaged in moderate or vigorous exertion or work, regeneration of the exhaled air by means of alkali peroxides results in an oxygen-nitrogen mixture containing, at least during the initial use period, an increased amount of oxygen (about 30 - 40% if the breathing bag was initially filled with air; 50 - 60% if it contained 2 - 3 liters of oxygen) compared to the normal air composition. In fact, it is known that even the inhalation of pure oxygen is more likely to produce advantageous than harmful effects.

However, It should be noted that whereas the reaction of KNaO_3 , water vapor and carbon dioxide, resulting in absorption of the last two, occurs immediately after use of the apparatus is started, regeneration of the oxygen consumed begins a little later, in about 2 - 3 minutes. This is probably due in part to the fact that the surface of the peroxide granules is exposed to moisture-laden air during the preparation, screening and filling operations. As a result, this surface is coated with sodium- or potassium hydroxide which absorbs the exhalation products without giving rise to oxygen evolution. In part, this is also due to the fact that the lower peroxides of the general formula M_2O_2 react with water vapor without immediately liberating oxygen; instead, a peroxide hydrate is formed which decomposes only at somewhat elevated temperatures generating oxygen. This causes discomfort and is noticeable only if a greater oxygen demand is created by faster movement or increased exertion immediately after use of the apparatus is started. This greater demand can be satisfied only after the peroxide has warmed up (on the average after 2 - 3 minutes). Under such conditions, the user has a feeling of oxygen deficiency during the first 2 - 3 minutes which disappears when he stops his premature exertion. The user is, therefore, instructed to make initial use of the apparatus in a resting position (standing, sitting, etc.) and to start, exertion (slow or fast walking, slow climbing, etc.) only after 2 - 3 minutes, i.e. when the apparatus is already sufficiently warm. If the breathing bag was not partially prefilled with oxygen, generated by the reaction with water according to the principle underlying the devices previously described, and the user started to exert himself immediately, he would be forced, by the low oxygen content of the breathing air, to cease this premature activity for a few

minutes and to breathe at rest. In our opinion, these minor limitations are preferable to the use of a very small unit for producing a few liters of oxygen by the reaction with water, which would complicate the apparatus.

As repeatedly mentioned, during the reaction the peroxide is heated to a high temperature which may reach 150 - 250° C depending on the breathing rate. In rescue devices of older design, where carbon dioxide is absorbed by aqueous caustic solutions, and particularly in equipment based on the system of Desgrez and Balthazard, however, the high temperature of the inhaled air was found to be objectionable; hence, complicated cooling devices are required although the absorption media are not heated much above 100° C. In tests conducted by us, on the other hand, the inhaled air was always found to be cool despite the markedly higher internal temperature of our apparatus. This unusual phenomenon is explained by the fact that the air regenerated with solid peroxide is nearly free of aqueous vapor and, hence, is dry when inhaled, whereas in older devices this air is nearly saturated with aqueous vapor and, hence, contains considerable moisture when inhaled. Considering that the specific heat of dry air is relatively low compared to the extremely high heat of vaporization of water and the equally high heat of condensation of aqueous vapor, it is readily understood that the heat content of a dry air stream at 40 - 50° C is very small and, hence, does not produce a sensation of heat in the body. Furthermore, dry air tends to vaporize the moisture from the mucous membranes thus absorbing heat. We measured the temperatures of the inhaled air in our apparatus at the mouthpiece at 5 minute intervals (experiment 15 in the attached table). Even after a 30-minute use period, the inhaled air still felt cool despite a temperature of 50° C.

However, when the peroxide filling of the apparatus is nearly exhausted, i. e., when the amount of sodium potassium carbonate present is large and that of alkali hydroxide is small, the air stream is no longer dried efficiently; therefore, it produces a heat sensation even though in many cases the air temperature is no longer at its maximum. This heat sensation is an automatic indication that the apparatus is near the end of its usefulness. /1434

As stated previously, the disadvantage of alkali peroxides is that the oxygen regenerated by exposure of their surface to water vapor or moist carbon dioxide entrains solid particles, consisting, for obvious reasons, mainly of sodium carbonate, which are so fine that they are not retained by conventional filters, dust traps, plate filters, etc. Irritation to the mucous membranes of the throat caused by this dust was clearly felt but was rarely so strong as to force the user to cough. We were able to eliminate this dust by use of a fine-pore asbestos filter, of course at the expense of breathing ease. Whereas, without the asbestos filter, the flow of air was extremely easy, use of the filter caused a clearly noticeable but not excessive resistance to air flow. The decision whether or not the feeling of mild irritation, lasting only about 15 min., is preferable to a persisting resistance to breathing, will, in our opinion, have to be based on practical experience. Damage to the mucous membranes is not an important factor considering that the apparatus is used only for emergency rescue and that the feeling of irritation ceases as soon as use of the apparatus is discontinued. The quantity of alkaline dust entrained by the air stream is definitely extremely small.

| Number | Duration Min. | Analysis of air in bag | | | | | Distance walked | Work done by climbing stairs | | Filling, g. | Initial of user | Physiological condition of user | Breathing bag con- tent be- fore use | Filter | Remarks |
|--------|------------------|------------------------|-----|-----------------|-----|---------|--|---------------------------------|------|--|--------------------|---|--|--|---|
| | | CO ₂ | O | CO ₂ | O | 45 min. | | | | | | | | | |
| 1 | 40 | 0% | 50% | 0% | — | — | — | 0 | 0 | 250 Na ₂ O ₂ | F. B. | good | about 7 l. O ₂ | asbestos | Apparatus of the type requiring supplemen- tary oxygen (Fig. 1) |
| 2 | 35 | 0 | 30 | 0 | 14% | — | 1450 | — | — | " | F. B. | " | " | " | |
| 3 | 40 | 0.2 | 55 | 0 | — | — | 550 | — | — | 250 NaKO ₃ medium coarse and coarse | F. B. | some irritation | none | none | Slow exertion Started using apparatus with lungs full |
| 4 | 46 | 0.6 | 52 | — | — | 12 | 2050 | — | — | 250 NaKO ₃ coarse and medium coarse | F. W. | some irritation, O ₂ deficiency after 4 min. | " | " | |
| 5 | 50 | 0.2 | 31 | 1.4 | 16 | — | 1600 | — | — | " | F. B. | some irritation, otherwise good | 2 l. O ₂ from H ₂ O reaction | " | Exertion started immediately and continued 1/2 hour; user rested the last 20 minutes. |
| 6 | 47 | 0 | 40 | — | — | 11 | 1200 | — | — | " | F. B. | consid. irrit. for 27 min. | empty | " | Immediate exertion with normally filled lungs; O ₂ deficiency after 2 min, hence user rested 2. |
| 7 | 30 | — | — | — | — | — | 1100 | 400 | 4467 | 250 NaKO coarse & medium coarse | F. B. | less irritation | about 4 l. of exhaled air | plate filters without asbes- tos | Bag partly filled by blowing air into it 3 times. Immediate exertion. User walked up and down three flights of stairs every 15 minutes. |
| 8 | 27 | 0.1 | — | — | — | — | 840 | 600 | 7968 | " | F. W. | consid. Irrit. at first some O ₂ def. | " | " | After every 50 minutes of walking, user walked up and down a flight of 22 steps |
| 9 | 40 | 0.2 | — | — | — | — | 1050 | 750 | 9720 | " | F. W. | " | " | " | Breathing in sitting position for 47 minutes followed by 17 minutes of exertion and climbing stairs using the same apparatus. |
| 10 | 45 | 0 | — | — | — | — | 1350 | 950 | 9880 | " | A. H. | " | " | " | |
| 11 | 47 | 0 | — | 0 | 21 | — | 0 | 0 | 0 | " | M. B. | excellent no irritation | " | " | Before use, user blew air into apparatus three times, then breathed 3 minutes at rest to allow apparatus to warm up. Test purposely discontinued after 30 minutes. |
| 12 | 30 | — | — | — | — | — | various undetermined ex- ertion, e. g., walking, running, climbing ladders crawling, etc. | | | " | F. W. | " | " | plate filters with asbestos filter | |
| 13 | 30 | — | — | — | — | — | | | | " | J. K. | " | " | " | Breathing in sitting position 1 hour 40 min. |
| 14 | 100 | — | — | — | — | — | 0 | 0 | 0 | " | P. A. | " | " | " | |
| 15 | 30 | — | — | — | — | — | 950 | — | — | " | F. B. | " | " | " | Temperature of inhaled air determined every 5 min: 35°, 38°, 42°, 44°, 47°, 49° C. Even so, air felt cool |
| 16 | 42 | 0.1 | 30 | 0 | 41 | 30 | 1250 | 0 | 0 | " | P. A. | " | " | " | Gas sampled from breathing tube during inhaling Initially 4 min. of breathing at rest. |

District Physician, Dr. J. Kaup, lecturer for hygiene at the Imperial-Royal Institute of Technology in Vienna, studied the physiological effects of the use of this apparatus from a medical and sanitary standpoint by careful observation of experiments 8, 9, 10, 11 and by personal use of the apparatus (experiment 13). His comments are as follows:

"From all these tests, it can be concluded that persons using this apparatus for 30 - 40 min. under conditions of average working exertion such as walking at a normal pace with occasional climbing, did not experience any difficulty. The breathing process was entirely normal. Lung irritation did not occur and the rise in pulse was commensurate with increased exertion. Apparently, oxygen evolution and absorption of the exhaled carbon dioxide during the use period foreseen for the apparatus were always sufficient for the needs of respiration, so that acute oxygen deficiency or excessive carbon dioxide concentrations were never observed."

The attached table collects data and observations for a number of tests carried out using devices of different design including those representing earlier development stages of our apparatus. Thus, tests 1 and 2 refer to models of the type shown in Fig. 1; the other tests were carried out with an apparatus of the type shown in Fig. 2, using sodium potassium peroxide. These tests provide a good insight into the effect of the degree of exertion on the duration of usability and the functioning of the apparatus. Tests 12 - 16 were carried out with an apparatus of the described final design. Since the composition of the inhaled gas seemed sufficiently characterized by numerous analyses carried out in preceding tests, and considering that the nature of the reaction remained the same, analysis of the inhaled air was essentially discontinued in later tests. In tests 12, 13 and 15, the test was discontinued after 30 min. although the apparatus could have been used longer. As indicated by the corresponding figures, the peroxide filling in the apparatus is capable of regenerating the inhaled air during a period of about 40 minutes under conditions of moderate exertion such as walking at a normal pace. It is of interest and quite useful that the use period of the apparatus increases markedly with decreasing exertion, so that, at complete rest, this period is more than three times that for conditions of exertion. It may be taken for granted that an apparatus filled with 250 g of sodium potassium peroxide has a use period of 30 - 90 minutes, depending on the conditions of exertion. This automatic adjustability represents an outstanding advantage over all devices using compressed oxygen (or air) which are designed either to produce a certain quantity of gas regardless of the degree of need or to permit the variation of this quantity within rather narrow limits by means of a complex mechanism assuming that the user actually has the dexterity, training and knowledge required to do so.

The apparatus weighs about 1 kg, and has a very advantageous volume (dimensions of housing A: height = 15 cm; diameter = 10 cm). These characteristics combined with the reliability and very moderate price of this apparatus compared to earlier equipment strongly indicate its suitability as a self-rescue device.

It should be stressed that self-rescue was the guiding principle of the design of our apparatus. Hence, it would be wrong and unreasonable to expect this apparatus to enable its user to do heavy work for long periods. Further studies

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and tests will show whether an apparatus suitable for such a purpose and based on our design principle can be developed. This work will be undertaken in cooperation with the known firm O. Neuperts Nachfolger (*) which is also commercially producing and marketing our apparatus.

*The devices sold by O. Neuperts Nachfolger, Vienna VIII, Bennoplatz 8, under the trade mark "Pneumatogen" are patented in all major countries.

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